International Journal of All Research Education and Scientific Methods (IJARESM),
ISSN: 2455-6211, Volume 13, Issue 5, May-2025, Available online at: www.ijaresm.com

Voltage & Frequency Control of Seig Used in Pico-Hydro Generation

Sahil S. Shinde[1], Shweta A. Patil[2], Pratik G. Zende[3], Kaustubh G. Khatavkar[4], Mr. P. D. More[5]

[1,2,3,4]UG Student, Electrical Eng. Department, ADCET, ASHTA
[5]Assistant Professor, Electrical Engineering Department, ADCET, ASHTA

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ABSTRACT

This project presents a detailed study on the utilization of Self-Excited Induction Generators (SEIGs) in Pico-Hydro power generation systems. Pico-Hydro systems, which typically generate less than 5 kW of power, are ideally suited for remote and rural areas where grid connectivity is either unavailable or unreliable. These systems offer a low-cost and sustainable solution for meeting the basic electricity needs of small communities. The core focus of this study is the Self-Excited Induction Generator, which has emerged as a highly efficient and robust alternative to traditional synchronous generators for small-scale renewable energy generation. SEIGs operate without the need for an external power supply or excitation system. Instead, they rely on residual magnetism in the rotor and external capacitors connected to the stator terminals to initiate and maintain voltage generation. This makes them particularly suitable for off-grid applications, where simplicity, reliability, and minimal maintenance are essential. The project investigates the basic operating principles of SEIGs, their construction, and the role of capacitive excitation establishing the required magnetic field. Through theoretical analysis and practical implementation, the project evaluates the performance of SEIGs under various load conditions, including resistive and inductive loads.

Keywords **- Self-Excited Induction Generator Pico-hydro power generation, Closed-loop voltage control, Capacitor, Reactive power.**

INTRODUCTION

Self-Excited Induction Generators (SEIGs) have emerged as a reliable and economical solution for small-scale renewable energy generation, especially in decentralized applications such as pico-hydro power systems. These generators are particularly suitable for rural and remote locations where grid connectivity is limited or nonexistent. Unlike conventional synchronous generators, SEIGs do not require an external power source for excitation. Instead, they utilize capacitor banks connected across the stator terminals to provide the necessary reactive power for voltage build-up and sustained operation.

The performance of SEIGs in pico-hydro setups is significantly influenced by variations in electrical load and water flow, which can affect the generator's terminal voltage. Voltage regulation is a critical aspect of SEIG operation and is typically managed by adjusting the excitation capacitance to respond to load changes. Improper matching between the load and excitation can lead to voltage instability, under-voltage, or over-voltage conditions, which can compromise the reliability of the power supply. To address this, recent research has focused on developing adaptive and intelligent voltage control strategies using microcontrollers, power electronic interfaces, and automatic switching of capacitor banks. These advanced techniques enhance the dynamic performance of SEIGs by maintaining a stable voltage output under varying load conditions. Real-time monitoring and feedback systems are also being employed to optimize the excitation level and ensure consistent voltage regulation.

LITERATURE SURVEY

The increasing interest in decentralized renewable energy systems has led to the adoption of Self-Excited Induction Generators (SEIGs) in pico-hydro and off-grid applications. A critical challenge in the effective use of SEIGs is the regulation of voltage and frequency under varying load and environmental conditions. Several researchers have proposed innovative methods to address these issues. Chermiti (2016) introduced a switched capacitor-based control approach for voltage regulation, demonstrating stability through theoretical and experimental validation. Haque (2009) focused on selecting appropriate capacitors for short-shunt SEIGs, ensuring reliable voltage control. Chanu (2024) developed a real-time impedance-based controller to regulate both voltage and frequency effectively. Nasir (2020) explored control strategies for SEIGs in wind turbine systems to enhance off-grid power reliability. To improve

frequency control, Hasanien (2009) implemented a fuzzy logic-based approach in hybrid setups, showing improved dynamic response. Rakib (2021) proposed an Arduino-based power factor correction system for reactive power compensation, while Talha (2023) designed an IoT-based monitoring and control framework for SEIG-based distribution networks.

METHODOLOGY

Capacitors

In the proposed system, capacitors (Figure 1) of 6 µF, 10 µF, 15 µF, and 20 µF are used to provide reactive power support to the Self-Excited Induction Generator (SEIG). These capacitors play a crucial role in maintaining voltage stability, especially under varying load conditions. By supplying the necessary reactive power, the capacitors help in sustaining the generator's excitation and improving the overall power quality. Depending on the voltage feedback, the combination of capacitors is adjusted to ensure that the output voltage remains within the desired range. This dynamic adjustment helps in enhancing system performance and ensuring reliable operation of the generator.[2]

Fig 1. Capacitors

Arduino

The Arduino (Figure 2) Uno is a microcontroller board based on the ATmega328P, commonly used for automation and control systems. In this project, which focuses on voltage regulation of a Self-Excited Induction Generator (SEIG), the Arduino plays a key role in monitoring and managing the system.

It receives real-time data from voltage sensors and processes it to determine if the generator output is within the desired range. [4]

Based on the sensed voltage, the Arduino decides which capacitor values (6µF, 10µF, 15µF, or 20µF) need to be connected or disconnected to maintain reactive power and stabilize the output voltage. Its fast response time, simple programming interface, and compatibility with various components make it ideal for managing automatic voltage control in renewable energy applications like SEIG-based power generation

Fig 2. Arduino

Relay:

The relay (Figure 3) used in this project operates at 12V DC on the control side and can handle AC voltages ranging from 0 to 400V on the output side. It acts as an electromechanical switch that enables or disables the connection of different capacitor banks to the Self-Excited Induction Generator (SEIG). In this system, the relay switching is controlled using a thyristor, which acts as an electronic switch triggered by the Arduino based on voltage feedback.[5]

Fig 3. Relay

DESIGN

Voltage

The voltage regulation (Figure 4) system operates on an embedded control principle using the Arduino Uno microcontroller. The process begins with the initialization of the Arduino Uno and voltage sensors. The system reads the phase-to-neutral voltage to monitor the supply condition.

If the measured voltage is below the desired threshold of 230V, the control logic calculates the required steps of capacitive compensation needed to boost the voltage. Based on the calculation, Arduino triggers transistors, which in turn activate relays. These relays connect appropriate steps of the capacitor bank (Capacitance) to the system, thereby adjusting the voltage. Once the voltage is corrected, feedback is sent back to the Arduino for continuous monitoring. If the voltage is already stable (≥230V), the system logs data or displays the voltage status. This process repeats in a continuous loop to maintain voltage regulation dynamically under varying load conditions. This design ensures automated, real-time voltage regulation using a combination of digital control, power electronics, and capacitive compensation techniques.[8]

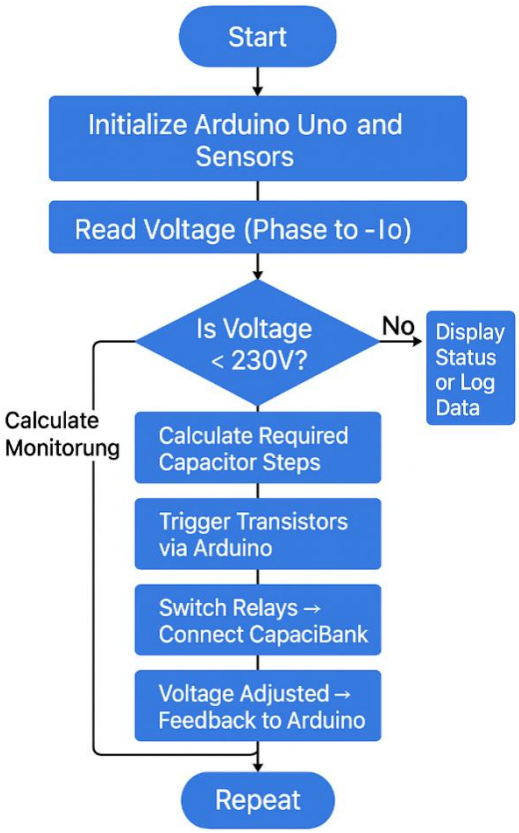

Fig 4 Methodology Flowchart(Voltage)

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Working

This project aims to maintain the terminal voltage of a Self-Excited Induction Generator (SEIG) (Figure 5) under varying load conditions. As SEIGs do not have external excitation sources, capacitors are used to provide the necessary reactive power for voltage buildup and regulation. The generator's output voltage is prone to drop due to load variations, so an automatic control system is designed to adjust the capacitor bank accordingly.

An Arduino UNO, based on the ATmega328P microcontroller, continuously monitors the SEIG output voltage through a voltage sensor. When the voltage drops below a predefined threshold or rises above it, the Arduino triggers thyristors to operate relays, which in turn switch capacitor banks of various ratings (6 µF, 10 µF, 15 µF, and 20 µF) into the circuit. [7]-[3]

Block Diagram Of Voltage Control Of Seig:

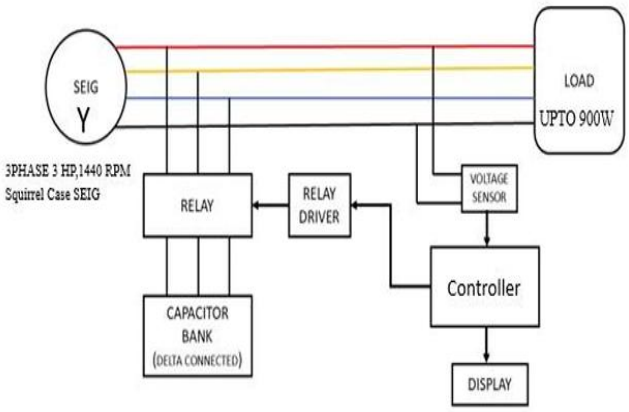

Fig 5. Block Diagram Of Voltage Control Of Seig

1. Self-Exited Induction Generator: - The SEIG is the main power generator driven by a prime mover It produces an C voltage output, which requires excitation for operation. Here we are using a Squirrel cage, 3 phase,3 Hp, 1440 rpm induction motor as generator.

2. Load: - The load represents the devices or systems consuming power generated by the SEIG. The voltage at the load terminals must be regulated to remain within the desired range.

3.Capacitor Bank (Delta Connected): -The capacitor bank provides the reactive power required to excite the SEIG. The capacitors are connected in a delta configuration for balanced three-phase operation. Here we are using capacitors of value 3µf,6µf,10µf,20µf respectively connected in Delta fashion

4. Relay: - The relay switches individual capacitors in or out of the circuit based on control signals. This adjusts the total excitation capacitance, which stabilizes the output voltage.

5. Relay Driver: - The relay driver circuit interfaces between the controller and the relays. It amplifies control signals from the controller Arduino (Figure 2) to operate the relays effectively

6. Voltage Sensor: - The voltage sensor measures the SEIG's output voltage and converts it into a signal suitable for the controller. It provides feedback to maintain voltage stability.

7. Controller: - The controller Arduino ATmega328 processes the voltage sensor data. It compares the sensed voltage with a reference value and determines the required adjustment to excitation. The controller generates control signals for the relay driver to modify the capacitor configuration.

8. Display: - The display unit shows real-time information such as the SEIG's output voltage. It allows monitoring of the system. Here we are using 16*2 LCD [1]

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Block Diagram Of Frequency Control Of Seig:

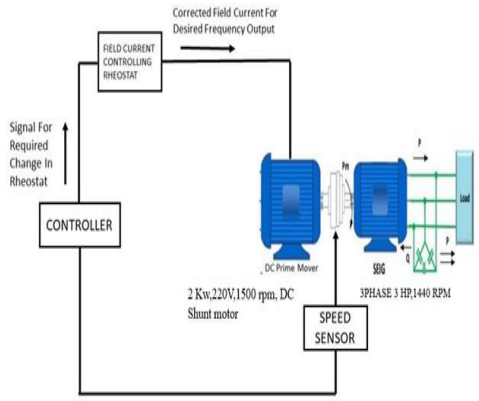

Fig 6. Block Diagram Of Frequency Control Of Seig

1. DC Prime Mover: A DC shunt motor rated at 2 kW, 220 V, and 1500 RPM serves as the prime mover. It provides the mechanical input (rotational motion) to drive the SEIG. The rotational speed of the prime mover directly affects the frequency of the SEIG output.

2. SEIG (Self-Excited Induction Generator): A 3-phase, 3 HP SEIG operating at 1440 RPM generates electrical power. It uses capacitors for self-excitation and is sensitive to speed and load variations.

3. Speed Sensor: Monitors the rotational speed of the DC prime mover. Provides real-time data to the controller for detecting speed deviations that may lead to frequency fluctuations.

4. Controller: Receives speed data from the sensor and compares it with the desired speed for maintaining frequency stability. Processes the required correction and sends a signal to the field current controlling rheostat.

5. Field Current Controlling Rheostat: Adjusts the field current dynamically based on the signal from the controller. Modulates the excitation current of the SEIG to correct frequency deviations and maintain stability.

6. Feedback Loop: This closed-loop system ensures continuous monitoring and adjustment of system parameters. The controller and rheostat work together to stabilize the SEIG frequency (Figure 6) in response to changes in load or prime mover speed.[4]

RESULT AND DISCUSSION

Reactive power calculations

Table 1 shows the calculated reactive power values corresponding to different capacitor ratings used in the system. These values were obtained using the formula Q=V^2 wc where V is the voltage, ωc is the angular frequency, and C is the capacitance.

Table.1 Reactive power calculations

Capacitance in (uF)	Reactive Power (Q=V^2 wc) in VAR
10	165.5
15	248.3
20	331.1
40	665.59

As observed in **Table 1**, increasing the capacitance leads to a proportional increase in reactive power, thereby enhancing the system's ability to maintain voltage under varying load conditions.

Discharge & Power Output Calculation:

The relationship between water head, discharge rate, and the corresponding power output was analyzed for the pico-hydro setup. The resulting power and energy values at different head levels are summarized in Table 2.

Table. 2 Discharge & Power Output Calculation

HEAD (meter)	DISCHARGE(m^3/sec)	POWER(KW)	ENERGY(KWh)
1	09724	6.23	0.104
1.2	1.0648	8.02	0.135
1.5	1.29	11.358	0.1893
2	1.38	17.5	0.2921

As shown in **Table 2**, an increase in head height and discharge volume results in a substantial rise in both power output and total energy generated, highlighting the system's efficiency at higher hydraulic inputs.

The integration of a capacitor bank effectively provided the necessary reactive power for self-excitation of the SEIG.

• Switching capacitors via relays-maintained voltage stability under varying load conditions. For light loads, fewer capacitors were required, while higher loads necessitated additional capacitors for voltage stabilization.

• Voltage variations were minimized, with the system successfully maintaining output voltage within a ±5% tolerance range under both steady-state and transient load conditions.

• The use of a capacitor bank demonstrated excellent adaptability to reactive power demands of the SEIG.

• The relay-based switching mechanism, controlled via an Arduino, ensured precise selection of capacitors based on load requirements.

• However, the response time of mechanical relays introduced minor delays during capacitor switching, which could be mitigated with faster electronic switches like solid-state relays.

CONCLUSION

The project effectively showcases a practical approach for managing voltage and frequency in Self-Excited Induction Generators (SEIGs) used in pico-hydro power systems. Voltage regulation is achieved through a capacitor bank operated via relay switching, which provides the required reactive power and maintains voltage within acceptable limits. For frequency stabilization, a speed sensor provides feedback to adjust the prime mover's speed using a rheostat, ensuring consistent frequency despite changes in load. This integrated control strategy enhances both the efficiency and dependability of SEIG-based systems, making them a viable option for off-grid and remote locations. In summary, the project emphasizes how smart control methods can significantly improve the stability and performance of small-scale renewable energy solutions, thereby promoting sustainable energy access in underserved regions.

Future Scope

The development of Self-Excited Induction Generators (SEIGs) in pico-hydro power systems presents several opportunities for future advancements in terms of performance, dependability, and broader usability. Incorporating emerging technologies such as solid-state controllers and hybrid renewable energy systems can significantly enhance the functionality of these setups, enabling more precise control, real-time system optimization, and improved scalability.

Advanced Control Techniques:
Transitioning from conventional rheostat and relay-based control methods to modern solid-state or PWM-based controllers can lead to faster response times.

Integrating SEIG-driven pico-hydro systems with additional renewable sources like solar or wind power can create a more dependable and balanced energy supply, especially in remote or off-grid locations.

Energy Storage Solutions:
The addition of battery storage units can help capture excess power during peak generation periods. This stored energy can be used during times of reduced water flow or increased load demand, thereby enhancing system stability and ensuring uninterrupted power delivery.

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